UCRL-93482
PREPRINT

NEW ELECTROMAGNETIC EFFECTS ASSOCIATED WITH CAVITY-BACKED APERTURES

Richard W. Ziolkowski

THIS PAPER WAS PREPARED FOR SUBMITTAL TO
1986-URSI International Symposium on
Electromagnetic Theory in Budapest

August 25-29, 1986

Lawrence Livermore National Laboratory

NEW ELECTROMAGNETIC EFFECTS ASSOCIATED WITH CAVITY-BACKED APERTURES

Richard W. Ziolkowski
Engineering Research Division
Lawrence Livermore National Laboratory
P.O. Box 5504, L-156
Livermore, CA 94550

ABSTRACT

A number of canonical problems that describe coupling through apertures into enclosed regions have been solved. The scattering data generated by these cavity-backed aperture (CBA) solutions share a common property: they are dominated by resonance features closely connected to the presence of the cavity. The behavior of these CBA resonance features will be described for variations in frequencies, angles of incidence, look angles, aperture sizes, and interior object characteristics. In particular, it will be demonstrated that standard bistatic cross-sections contain information about the interior of the cavity.

1. INTRODUCTION

Because they describe coupling via apertures into enclosed regions *and* scattering from reflector structures having edges and nontrivial geometries, the importance of canonical electromagnetic cavity-backed aperture problems can not be understated. They provide a basic means with which fundamental aperture coupling and reflector physics can be studied in detail; they can be used to construct and/or validate approximate models or general engineering analysis and design "rules of thumb" that can be applied to more general apertures and scattering objects; and they aid in the development of improved numerical techniques especially near the edges of the apertures or reflectors where discontinuities appear and where those methods may encounter difficulties. Moreover, accurate canonical solutions of this type provide standards to which general purpose numerical code results can be compared.

A number of canonical problems that describe coupling through apertures into enclosed regions have been solved recently with the generalized dual series (GDS) approach and have been reported[1-8]. These include the two-dimensional solutions to the scattering of E- and H- polarized plane waves from an empty infinite circular cylinder having an infinite axial slot [1,2] and from one that encloses an infinite concentric [3,4] or off-set impedance cylinder [5], and the three-dimensional solutions to the plane wave scattering from an empty open spherical shell with a circular aperture [6,7], and from an open spherical shell with a circular aperture enclosing either a concentric metallic or dielectric sphere.[8] These problems have been studied extensively to determine the effects on the aperture coupling and scattering of variations in the polarization, frequency, angle of incidence, aperture size, and interior object characteristics. The GDS solutions are systematic and inherently contain the behavior near the rim of the aperture required by Meixner's edge conditions. They can handle small to large ratios of cylinder radius to wavelength and arbitrary angles of incidence without additional special considerations. The two-dimensional slit cylinder problems have proved to be valuable because with a variation of a single parameter, the impedance, the slit cylinder can be empty or made to enclose a perfectly conducting or lossy wire. The three-dimensional open spherical shell problems involve a finite scatterer and have proved to be valuable in determining which of the recognized coupling effects are not tied to the two-dimensional nature of the slit cylinder problems.

2. RESULTS

A cross-section of the generic problem configuration is shown in Figure 1. The open scatterer has radius a, the interior object has radius b. Half the angular extent of the aperture is measured by the angle Θ_{ap}.

It has been found that resonance features corresponding to the presence of the interior cavity dominate all of the the aperture coupling and the scattering results. These include the currents induced on the interior conductors and the open scatterer, the fields in the aperture, the energy captured by the open cavity, and the bistatic cross-sections. The locations in frequency of the cavity-backed aperture (CBA) resonances and the resultant current and field patterns at those values can be identified with corresponding closed-cavity resonance locations and patterns.

Fig. 2 shows the radar cross-sections for a plane wave normally incident into the circular aperture of an open spherical shell with $1.0m$ and $\Theta_{ap} = 10^\circ$ that is either (a) empty (–) or encloses a concentric sphere of radius $0.3m$ that is either (b) perfectly conducting (**) or (c) a homogeneous, lossless dielectric with relative permittivity $\epsilon_r = 3.0$ (++). For the empty interior case the peaks of the anti-resonance features occur at ka = 2.740, 3.860, 4.488, and

4.950. These are slightly lower than the corresponding closed cavity resonance locations: 2.744, 3.870, 4.493, and 4.973; due to the detuning of the cavity by the aperture. The anti-resonance features in the metal and dielectric inner sphere cases occur, respectively, at ka = 2.410, 3.783, 4.929, 5.036, and 5.341; and ka = 2.583, 3.822, 4.271, 4.939, and 5.326. For the empty open sphere these CBA features correspond to the TM_{11}, TM_{21}, TE_{11}, and TM_{31} modes; for the loaded open spheres they correspond to the TM_{11}, TM_{21}, TE_{11}, TM_{31}, and TM_{12} modes. These mode assignments were made by tracking the resonance locations from the corresponding closed sphere to the present open sphere cases.[8]

The resonance peaks in these cross-sections are indicative of a reradiation phenomena that is associated with the cavity-backed nature of the aperture. The currents induced on the sphere and consequently the scattered fields experience a π-phase shift as ka passes through one of these CBA resonances. Concurrently the energy captured in the interior of the open spherical shell dramatically increases just below the resonance point and decreases just above it. Thus a scattered field, whose amplitude is enhanced by the energy reradiated from the cavity, is created that at different look angles either constructively or destructively interferes with the incident field. This results in the distinctive anti-resonance features present in the radar cross-sections. For small apertures they are very narrow which is indicative of the extremely high Q nature of the cavity. Increasing the aperture size broadens them and their locations are translated to lower ka values corresponding to an increased detuning of the cavity.

These anti-resonance features are also the predominant form of the resonances in frequency scans of the average axial current induced by an E-pol plane wave on a wire enclosed by a slit cylinder. This is demonstrated in Fig. 3 where the *log* of the magnitude of the average axial current is plotted against the *log* of the frequency. The radii of the slit cylinder and the interior wire are $b = 1.0m$ and $a = 0.1m$, respectively. The slit cylinder has a $2\Theta_{ap} = 2.0°$ aperture, and the plane wave is normally incident into it. The particular mode pattern established in the interior of the slit cylinder determines the form of the resonance.[4] The "standard" form of resonance peak occurs only at the TM_{0n} coax mode frequencies. For example, the resonant peaks at 8.199 and 8.515 correspond to the TM_{01} and TM_{02} modes. On the other hand, the anti-resonances at 8.274, 8.389, 8.483, 8.544, and 8.556 correspond to the TM_{11}, TM_{21}, TM_{31}, TM_{12}, and TM_{41} modes. These anti-resonance features completely dominate the current scans as the aperture is widened. For a larger aperture the "standard" resonance peaks become substantially detuned while the anti-resonance structures become broader with more pronounced minimums. In addition, the background level of the current rises because the incident field penetrates more readily into the interior of the cavity.

The large shifts in the locations of the CBA resonances depending on the characteristics of the interior load observed in Fig. 2 are typical. As the size of the interior load is increased, very large translations of the CBA resonance locations occur. As a result, one may observe the sequence in which resonances appear to be altered or even a disappearance of some resonances in a fixed kb interval. As the relative permittivity of an interior dielectric sphere is increased, the number resonances found at the lower ka values is drastically increased. Mode splitting, as well as mode translation, occurs when a wire, interior to a slit cylinder, is moved off-axis.

These resonance features are also found in the bistatic cross-sections at the same relative positions for at all look angles. This is true even for non-normal incidence. As one might expect, the shapes and sizes of the individual resonance peaks vary with the angle of incidence and the relative bistatic look angles. The anti-resonance peaks in the empty open spherical shell radar cross-sections have been observed experimentally[9].

3. CONCLUSIONS

Parameter studies of the generalized dual series solutions of several cavity-backed aperture canonical problems are enhancing our understanding of the aperture coupling and scattering processes. The presence of the resonance features in the interior wire currents and in the scattering cross-sections are extremely interesting. What role, if any, the current resonances may play in EMP damage mechanisms is being examined. The cross-section resonances indicate that *for cavity-backed apertures there is interior information contained in the exterior scattering data.* The dependence of the location of these peaks on the interior structure and their presence at all look angles may have very important ramifications for object identification applications.

This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

REFERENCES

[1] R. W. Ziolkowski, "N-Series problems and the coupling of electromagnetic waves to apertures: A Riemann-Hilbert approach", *SIAM J. Math Anal.*, Vol. 16(2), Mar. 1985.

[2] W. A. Johnson and R. W. Ziolkowski, "The scattering of an H-polarized plane wave from an axially slotted infinite cylinder: a dual series approach", *Radio Science*, Vol. 19(1), 275-291, Jan. 1984.

[3] R. W. Ziolkowski , W. A. Johnson, and K. F. Casey, "Applications of Riemann- Hilbert problem techniques to electromagnetic coupling through apertures", *Radio Science*, Vol. 19(11), Dec. 1984.

[4] R. W. Ziolkowski and J. B. Grant, "Scattering from cavity-backed apertures: The generalized dual series solution of the concentrically loaded E-pol slit cylinder problem", submitted to IEEE Trans. Antennas Prop., Mar. 1986.

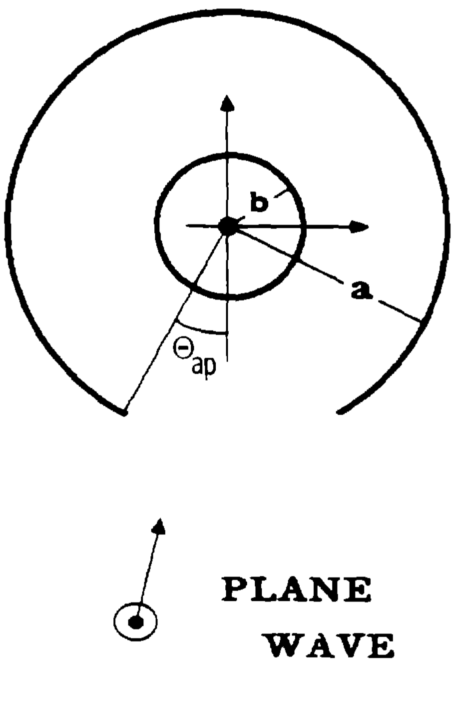
[5] R. W. Ziolkowski and R. F. Schmucker, "Scattering from a slit cylinder enclosing an off-set impedance surface", National Radio Science Meeting, U.R.S.I. B8-8, Boulder, CO, Jan. 1986.

[6] R. W. Ziolkowski and W. A. Johnson, "Electromagnetic Scattering of an Arbitrary Plane Wave from a Spherical Shell with a Circular Aperture", submitted to J. Math. Phys. July, 1985.

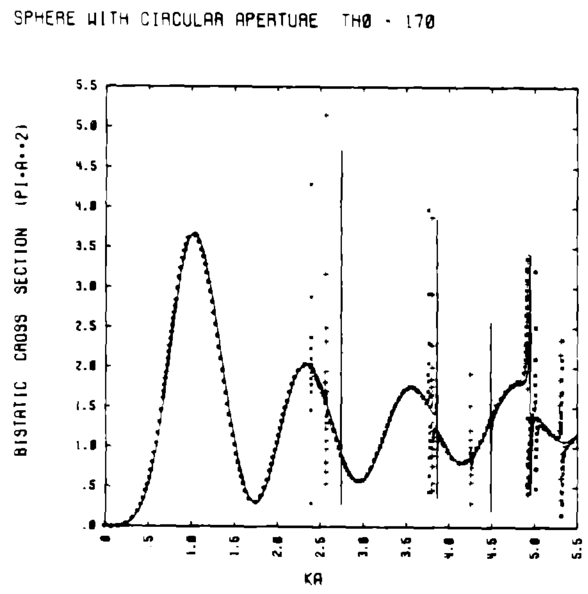
[7] R. W. Ziolkowski, "Scattering from a spherical shell with a circular aperture: cross-sections and energy storage for a normally incident plane wave", National Radio Science Meeting, U.R.S.I. IRC-6, Vancouver, B. C., June 1985.

[8] R. W. Ziolkowski, D. M. Peplinski, and L. F. Libelo, "Scattering from an open spherical shell having a circular aperture and enclosing a metallic or dielectric sphere", National Radio Science Meeting, U.R.S.I. B8-9, Boulder, CO, Jan. 1986.

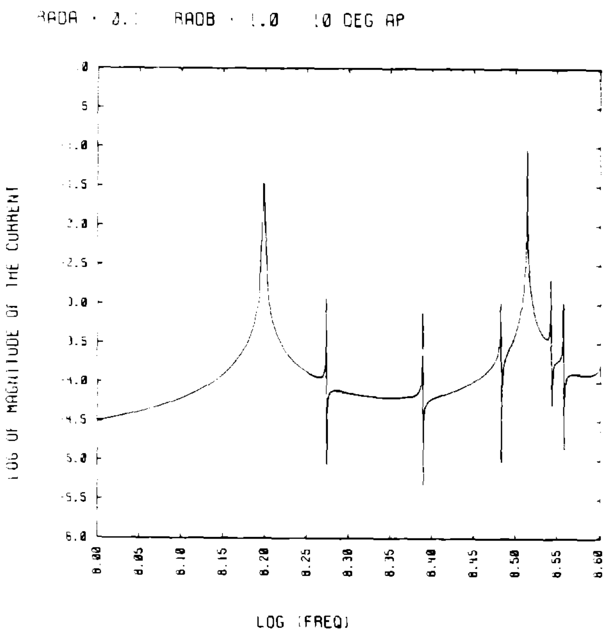
[9] S. Chang and T. B. A. Senior, "Scattering by a Spherical Shell with a Circular Aperture", AFWL Interaction Notes, Note 141. Apr. 1969.



1. The generic configuration of the scattering of a plane wave from a cavity-backed aperture with an interior load is depicted.



2. The presence of interior information in the exterior scattering data is demonstrated with ka scans of the radar cross-sections for a plane wave normally incident into a 10° aperture of a $1.0m$ open spherical shell that is either empty (–) or encloses either a concentric metallic (**) or $\epsilon_r = 3.0$ dielectric sphere (++) with $b = 0.3m$.



3. Cavity-backed aperture (CBA) resonances also occur in frequency scans of the average axial current induced by an E-pol plane wave on a perfectly conducting wir- enclosed by a slit cylinder. The radii of the slit cylinder and the interior wire are $b = 1.0m$ and $a = 0.1m$, respectively. The slit cylinder has a $2\Theta_{ap} = 2.0°$ aperture, and the plane wave is normally incident into it. The frequency is varied from 100 - 400 MHz.